Study of the intensity and driving factors of land use/cover change in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River region, Qinghai-Tibet Plateau of China

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Abstract: Land use/land cover (LULC) is an important part of exploring the interaction between natural environment and human activities and achieving regional sustainable development. Based on the data of LULC types (cropland, forest land, grassland, built-up land, and unused land) from 1990 to 2015, we analysed the intensity and driving factors of land use/cover change (LUCC) in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River (YNL) region, Qinghai-Tibet Plateau of China, using intensity analysis method, cross-linking table method, and spatial econometric model. The results showed that LUCC in the YNL region was nonstationary from 1990 to 2015, showing a change pattern with "fast-slow-fast" and "U-shaped". Built-up land showed a steady increase pattern, while cropland showed a steady decrease pattern. The gain of built-up land mainly came from the loss of cropland. The transition pattern of LUCC in the YNL region was relatively single and stable during 1990–2015. The transition pattern from cropland and forest land to built-up land was a systematic change process of tendency and the transition pattern from grassland and unused land to cropland was a systematic change process of avoidance. The transition process of LUCC was the result of the combined effect of natural environment and social economic development in the YNL region. This study reveals the impact of ecological environment problems caused by human activities on the land resource system and provides scientific support for the study of ecological environment change and sustainable development of the Qinghai-Tibet Plateau.

Keywords: land use/cover change; intensity analysis; driving factors; Yarlung Zangbo River; Nyang Qu River; Lhasa River; Qinghai-Tibet Plateau

1 Introduction

Land use/land cover (LULC) is the most direct manifestation of the impact of human activities on natural environment. It is one of the important factors that affect the service function and stability of terrestrial ecosystems, and has a crucial impact on the regional and global ecological environment (Chen et al., 2015; Tsai et al., 2015). Land use/cover change (LUCC) is a

comprehensive index that objectively reflects the impact and degree of human activities on the land surface, and it also plays an important role in studying carbon, nitrogen, water, and other material cycles as well as biodiversity and ecosystem service functions on a regional scale (Tsai et al., 2015; Ghurah et al., 2018; Albert et al., 2020; Aytursun et al., 2020). The process and intensity of LUCC are important factors for exploring the interaction between natural environment and human activities and achieving regional sustainable development. The driving factors of LUCC can help us to understand the interaction and feedback mechanism of the human-land relationship (Li et al., 2015; Tian et al., 2020).

Previous research on LUCC mainly focuses on simulation prediction, landscape patterns, and ecological environment effects, paying more attention to LUCC model rather than change process and concentrating on simulation rather than actual quantity of LUCC. There is a lack of LUCC processes and measurement analyses in continuous time series (Rimal et al., 2019; Wei et al., 2021; Xiong et al., 2021). At present, the research methods regarding LUCC processes mainly focus on land use transfer matrix and land use dynamic degree. Land use transfer matrix directly analyses the characteristics of land quantity, structure, and transformation direction in a matrix correlation table, while land use dynamic degree only explores the change rate of LULC types. Neither of them explores the evolution rule of LUCC processes in continuous time series or multiple time intervals (Romero-Rui et al., 2011; Dong et al., 2020; Zhang et al., 2020). Aldwaik and Pontius (2012) proposed the intensity analysis of LUCC, which is a mathematical explanatory framework of the top-down hierarchical level used to analyse the intensity and stability of LUCC in continuous time series. Numerous scholars have used the framework to analyse the intensity and stability of LUCC in some regions, such as Japan, Indonesia, and China (Shoyama et al., 2010; Pontius et al., 2013; Sun et al., 2016). Research on the driving factors of LUCC mainly focuses on the impact of natural and human factors, without considering the characteristics of spatial dependence or spatial autocorrelation of land use spatial data (Wang et al., 2020; Zhu et al., 2020; Dong et al., 2021). In view of this, scholars introduced the theory and method of spatial econometric model, which fully considers the spatial effect of LUCC and helps to scientifically analyse the driving factors behind LUCC (Lu et al., 2019).

The Qinghai-Tibet Plateau of China is a typical ecologically fragile and sensitive area, and LUCC in this region has a significant impact on the regional and global ecological environment (Gao et al., 2021). The land area in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River (YNL) region is 6.65×10^4 km^2, accounting for only 5.4% of the total land area of Tibet Autonomous Region, China, but it is the main concentration area for economic construction, agricultural resource development, and population in Tibet (Fan et al., 2015). As of 2015, the population and GDP in this region accounted for 57.2% and 57.9% of the total population and GDP in Tibet, respectively. The continuous rapid economic and social development as well as urbanization have led to increasingly drastic LUCC influenced by human activities and large change in LULC types (Tang et al., 2011; Wu et al., 2016; Zhang, 2016). Therefore, we selected the YNL region as the study area and analysed the intensity and driving factors of LUCC during 1990–2015 by using intensity analysis method, cross-linking table method, and spatial econometric model. The aim of the study is to reveal the impact of natural environment and human activities on land resource system by analysing LUCC in typical areas and to provide scientific support for the study of ecological environment change and sustainable development on the Qinghai-Tibet Plateau.

2 Materials and methods

2.1 Study area

The YNL region is located in the south central part of Tibet Autonomous Region, China, and in the valley of the middle reaches of the Yarlung Zangbo River, Lhasa River, and Nyang Qu River (Fig. 1). The average altitude of the region is between 3200 and 4600 m, which is a relatively flat

topography. The study area includes Lhasa City, Xigaze City, and Shannan Prefecture of Tibet. Before 1990, the population scale in the YNL region is relatively small, urbanization is in its initial stage, and the development of agriculture and animal husbandry is the main factor affecting the ecological environment. The YNL region, as a breakthrough in Tibet's economic and social development, has become the hinterland of Tibet and an important grain-producing area through the construction of water conservancy, the transformation of medium- and low-yield fields, and returning cropland to forest and grassland since the 1990s. Social and economic development has entered a period of sustained and rapid development. LUCC affected by human activities is becoming increasingly intense, and LULC types have significantly changed since the 1990s (Zhang et al., 2017).
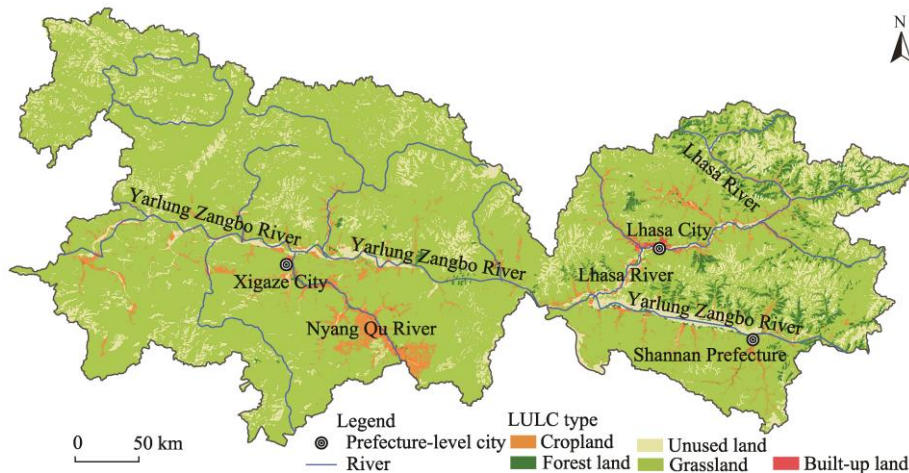

Fig. 1　Land use/land cover (LULC) types in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River (YNL) region in 2015. LULC types data were obtained from the Resource and Environmental Science Data Centre of the Chinese Academy of Sciences (http://www.resdc.cn).

2.2　Data source

1990 was a critical time and a turning point for rapid economic and social development in the YNL region, resulting in dramatic change in LULC types. Therefore, we selected four periods of LULC types data (1990, 2000, 2010, and 2015) to analyse and discuss the intensity and transition pattern of LUCC in the past 25 years. LULC types data were obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn), with the spatial resolution of 30 m. According to utilization attributes of land resources, we divided LULC types into cropland, forest land, grassland, built-up land, and unused land. Considering the structure characteristics of LULC types in the YNL region, we combined unused land and water area into unused land for analysis and calculation.

2.3　Methods

2.3.1　Intensity analysis method

Intensity analysis method, a top-down mathematical framework, includes three different levels: interval level, category level, and transition level (Aldwaik and Pontius, 2012). The process of LUCC and the interaction mechanism are explained by analysing the intensity characteristics of LUCC at the three different levels. Interval level reflects LUCC in each time interval (Table 1). Stationarity analysis is performed in each time interval by comparing the intensity of LUCC (S_t) and the uniform intensity (U) (Table 1). When S_t is greater than U, LUCC is faster, while S_t is less than U, LUCC is slower. If S_t is uniformly distributed throughout the time interval, then LUCC is stable; otherwise, it is unstable. Category level analyses the intensity change of each LULC type over a specific time interval. If annual gain intensity (G_{tj}) or annual loss intensity (L_{ti}) is greater than S_t, then the change of LULC type is active; otherwise, it is dormant. Transition level examines

the transition of the gaining or losing LULC type. Transition intensity of LULC type n gains from LULC type i (R_{tin}) is compared with the uniform intensity (W_{tn}) and transition intensity of LULC type m loses to LULC type j (Q_{tmj}) is compared with the uniform intensity (V_{tm}). When R_{tin} is higher than W_{tn}, the gain of LULC type n comes from LULC type i; while Q_{tmj} is higher than V_{tm}, the loss of LULC type m is transformed into LULC type j (Aldwaik and Pontius, 2012; Gitau and Bailey, 2012; Geng et al., 2018; Niu et al., 2021).

Table 1 Calculation formula of intensity analysis of land use/cover change (LUCC) at interval level, category level, and transition level

Intensity analysis	Characterisation index	Calculation formula
Interval level	Intensity of LUCC in each time interval	$S_t = \dfrac{\left\{\sum\limits_{j=1}^{J}\left[\left(\sum\limits_{i=1}^{J}C_{tij}\right)-C_{tjj}\right]\right\} \div \left[\sum\limits_{j=1}^{J}\left(\sum\limits_{i=1}^{J}C_{tij}\right)\right]}{Y_{t+1}-Y_t} \times 100\%$
	Uniform intensity within the overall time interval	$U = \dfrac{\sum\limits_{t=1}^{T-1}\left\{\sum\limits_{j=1}^{J}\left[\left(\sum\limits_{i=1}^{J}C_{tij}\right)-C_{tjj}\right]\right\} \div \left[\sum\limits_{j=1}^{J}\left(\sum\limits_{i=1}^{J}C_{tij}\right)\right]}{Y_T-Y_1} \times 100\%$
Category level	Annual gain intensity	$G_{tj} = \dfrac{\left[\left(\sum\limits_{i=1}^{J}C_{tij}\right)-C_{jj}\right] \div (Y_{t+1}-Y_t)}{\sum\limits_{i=1}^{J}C_{tij}} \times 100\%$
	Annual loss intensity	$L_{ti} = \dfrac{\left[\left(\sum\limits_{j=1}^{J}C_{tij}\right)-C_{ii}\right] \div (Y_{t+1}-Y_t)}{\sum\limits_{j=1}^{J}C_{tij}} \times 100\%$
Transition level	Transition intensity of LULC type n gains from LULC type i in a particular time interval	$R_{tin} = \dfrac{C_{tin} \div (Y_{t+1}-Y_t)}{\sum\limits_{j=1}^{J}C_{tij}} \times 100\%$
	The uniform transition intensity of LULC type n from other LULC types in a particular time interval	$W_{tn} = \dfrac{\left[\left(\sum\limits_{i=1}^{J}C_{tin}\right)-C_{tnn}\right] \div (Y_{t+1}-Y_t)}{\sum\limits_{j=1}^{J}\left[\left(\sum\limits_{i=1}^{j}C_{tij}\right)-C_{tnj}\right]} \times 100\%$
	Transition intensity of LULC type m loses to LULC type j in a particular time interval	$Q_{tmj} = \dfrac{C_{tmj} \div (Y_{t+1}-Y_t)}{\sum\limits_{i=1}^{J}C_{tij}} \times 100\%$
	The uniform transition intensity of LULC type m to other LULC types in a particular time interval	$V_{tm} = \dfrac{\left[\left(\sum\limits_{j=1}^{J}C_{tmj}\right)-C_{tmm}\right] \div (Y_{t+1}-Y_t)}{\sum\limits_{i=1}^{J}\left[\left(\sum\limits_{j=1}^{j}C_{tij}\right)-C_{tim}\right]} \times 100\%$

Note: J, the number of LULC types; i, LULC type i; j, LULC type j; n, LULC type n; m, LULC type m; T, the number of time points; t, time point ranging from 1 to T; Y_t, year at time point t; C_{tij}, area that transformed from LULC type i at time Y_t to LULC type j at time Y_{t+1}; S_t, annual uniform intensity of LUCC during time interval $[Y_t, Y_{t+1}]$; U, uniform intensity in each time interval of $[Y_1, Y_T]$; G_{tj}, annual gain intensity of LULC type j during time interval $[Y_t, Y_{t+1}]$; L_{ti}, annual loss intensity of LULC type i during time interval $[Y_t, Y_{t+1}]$; C_{tin}, area that transition from LULC type i to LULC type n during time interval $[Y_t, Y_{t+1}]$; C_{tmj}, area that transition from LULC type m to LULC type j during time interval $[Y_t, Y_{t+1}]$; R_{tin}, annual transition intensity from LULC type i to LULC type n during time interval $[Y_t, Y_{t+1}]$; W_{tn}, uniform intensity of transition to LULC type n from all non-n LULC type at time Y_t during time interval $[Y_t, Y_{t+1}]$; Q_{tmj}, annual transition intensity of transition from LULC type m to LULC type j during time interval $[Y_t, Y_{t+1}]$; V_{tm}, uniform intensity of transition from LULC type m to all non-m LULC type at time Y_{t+1} during time interval $[Y_t, Y_{t+1}]$.

2.3.2 Cross-linking table method

The systematicity and stability of LULC types transition process are mainly identified by cross-linking table method, which is based on the gain and losse of LULC types at transition level in intensity analysis. It is a grid matrix table that identifies the transition pattern characteristics

between LULC type i at the beginning of each period and LULC type j at the end of each period. The loss of LULC type i tends to be transformed into LULC type j, and the gain of LULC type j also tends to be transformed from the loss of LULC type i in continuous time intervals, then, it can be considered that the transition from LULC type i to LULC type j is a systematic change process of tendency. The gain of LULC type j avoids transition from LULC type i, and the loss of LULC type i also avoids transform into LULC type j in continuous time intervals, then, it can be considered that the transition from LULC type i to LULC type j is a systematic change process of avoidance (Yang et al., 2019).

2.3.3 Spatial econometric model

We used a spatial econometric model to analyse the relationship between LUCC and driving factors in considering the characteristics of research data (cross-sectional data). The spatial econometric model fully considers the spatial effects between LULC grids, and take the spatial interaction between grids as an independent variable in the model, which can effectively avoid the deviation or invalidity of the estimated values of the ordinary least squares (Han and Zou, 2019; Wang et al., 2019). Spatial lag model and spatial error model are commonly used spatial econometric models, the former is mainly used when dependent variables have obvious spatial correlation, while the latter represents the influence of unexplained or unpredictable variables (Burridge,1980; Anselin, 1988). First-order adjacencies are selected to construct the spatial weight matrix of the spatial econometric model.

$$\text{Spatial lag model:} \qquad Y = \rho W_Y + \chi\beta + \varepsilon, \qquad (1)$$

$$\text{Spatial error model:} \qquad Y = \chi\beta + \varepsilon, \qquad (2)$$

$$\varepsilon = \lambda W\varepsilon + \mu, \qquad (3)$$

where Y is the dependent variable; ρ is the spatial lag term coefficient; W_Y is spatial lag term; χ is the explanatory variable; β is the parameter coefficient; ε is the error term; W is the spatial weight matrix; λ is the autoregressive parameter; and μ is the random error vector of the normal distribution. For variables with significant spatial correlation, Lagrange multiplier (error), Lagrange multiplier (lag), Robust LM (lag), and Robust LM (error) were analysed using the likelihood method and Anselin's discriminant criterion (Yang et al., 2019).

If spatial lag model is more statistically significant than spatial error model, then spatial lag model is selected; otherwise, spatial error model is selected. If neither are significant, then the ordinary least square is selected (Anselin, 2005; Gallo and Chasco, 2015).

We used OriginPro and Excel software to analyse the intensity and transition process of LUCC. The spatial correlation indices and spatial econometric model parameters were calculated using Geoda software.

3 Results

3.1 Characteristics of land use/cover change (LUCC)

From 1990 to 2015, the area of different LULC types in the YNL region was ranked as follows: grassland>unused land>cropland>forest land>built-up land (Table 2). The area of grassland and unused land accounted for approximately 94.3% of the total area, which was the main LULC types in the region. From the analysis of LULC types and change in area, the growth trend of built-up land was significant, from 94.74 km^2 in 1990 to 165.96 km^2 in 2015. The area of forest land increased from 1973.64 km^2 in 1990 to 2103.01 km^2 in 2000 and then presented a continuously decrease trend. The area of grassland and cropland showed a decrease trend from 1990 to 2015. Compared with other LULC types, change in area was more complex in unused land; it decreased from 1990 to 2000, remained basically unchanged from 2000 to 2010, and increased from 2010 to 2015 (Table 2).

From the analysis of change in the proportion of LULC types, the percentage of built-up land area in the YNL region increased from 0.13% to 0.22% during 1990–2015, indicating that urban

space was expanding rapidly with rapid development of urbanization. The percentage of forest land area remained stable since 2000 (2.82%). The percentage of grassland area decreased from 79.93% to 79.77% from 1990 to 2015. The percentage of cropland area decreased from 3.66% to 3.61%. The comprehensive analysis showed that the great change has taken place in built-up land and cropland greatly affected by human activities in the YNL region (Table 2).

Table 2 Change in area and percentage of land use/land cover (LULC) types in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River (YNL) region in 1990, 2000, 2010, and 2015

Year	Cropland		Forest land		Grassland		Built-up land		Unused land	
	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)
1990	2729.81	3.66	1973.64	2.65	59,570.35	79.93	94.74	0.13	10,155.46	13.63
2000	2723.88	3.66	2103.01	2.82	59,495.49	79.83	110.59	0.15	10,091.03	13.54
2010	2711.28	3.64	2102.77	2.82	59,485.41	79.82	133.97	0.18	10,090.57	13.54
2015	2689.30	3.61	2097.70	2.82	59,445.90	79.77	165.96	0.22	10,125.13	13.59

3.2 Intensity analysis of LUCC

3.2.1 Intensity analysis of LUCC at interval level

Intensity analysis at interval level was to clarify the intensity change in a specific interval within the overall time interval. LUCC in the YNL region was nonstationary from 1990 to 2015, showing a change pattern with "fast-slow-fast" and "U-shaped" (Fig. 2). Specifically, the intensity of LUCC during 1990–2000 and 2010–2015 was greater than the uniform intensity, indicating that LUCC in the two periods was rapid. The intensity of LUCC during 2000–2010 was less than the uniform intensity, indicating that LUCC was slow in this period. The area and intensity of LUCC shown in Figure 2 were highly consistent with the actual situation. During 1991–2000, some key development and construction were carried out in the YNL region, which was the main reason for the intensity of LUCC.
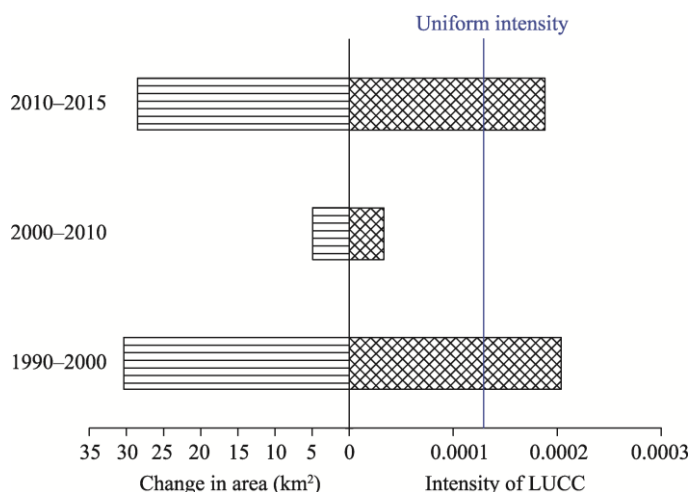

Fig. 2 Change in area and intensity of LUCC at interval level in the YNL region during 1990–2000, 2000–2010, and 2010–2015

3.2.2 Intensity analysis of LUCC at category level

Intensity analysis at category level was mainly to detect the stability of each LULC type within a particular time interval. Figure 3 showed that the annual gain intensity of built-up land presented an upward trend and it was significantly higher than the uniform intensity of LUCC in the three periods of 1990–2000, 2000–2010, and 2010–2015, indicating a relatively active increase state. The annual loss intensity of built-up land was also higher than the uniform intensity of LUCC in the three periods, but the annual gain intensity was significantly higher than the annual loss

intensity, suggesting a steady growth pattern throughout the study period (Fig. 3). In contrast, the annual loss intensity of cropland was significantly higher than the uniform intensity of LUCC, indicating a stable reduction pattern throughout the study period (Fig. 3). The annual loss intensity of grasslands was less than the uniform intensity of LUCC, but the annual loss intensity was higher than the annual gain intensity, indicating that grasslands were still dominated by the losing. From 1990 to 2000, the annual gain intensity of forest land was higher than the uniform intensity, and the annual loss intensity was lower than the uniform intensity, but the annual loss intensity of forest land was significantly higher than the uniform intensity from 2000 to 2015 (Fig. 3). For unused land, except that the annual loss intensity was higher than the uniform intensity of LUCC from 1990 to 2000, the annual loss intensity and gain intensity in the other two periods were lower than the uniform intensity of LUCC and in a stable state (Fig. 3).
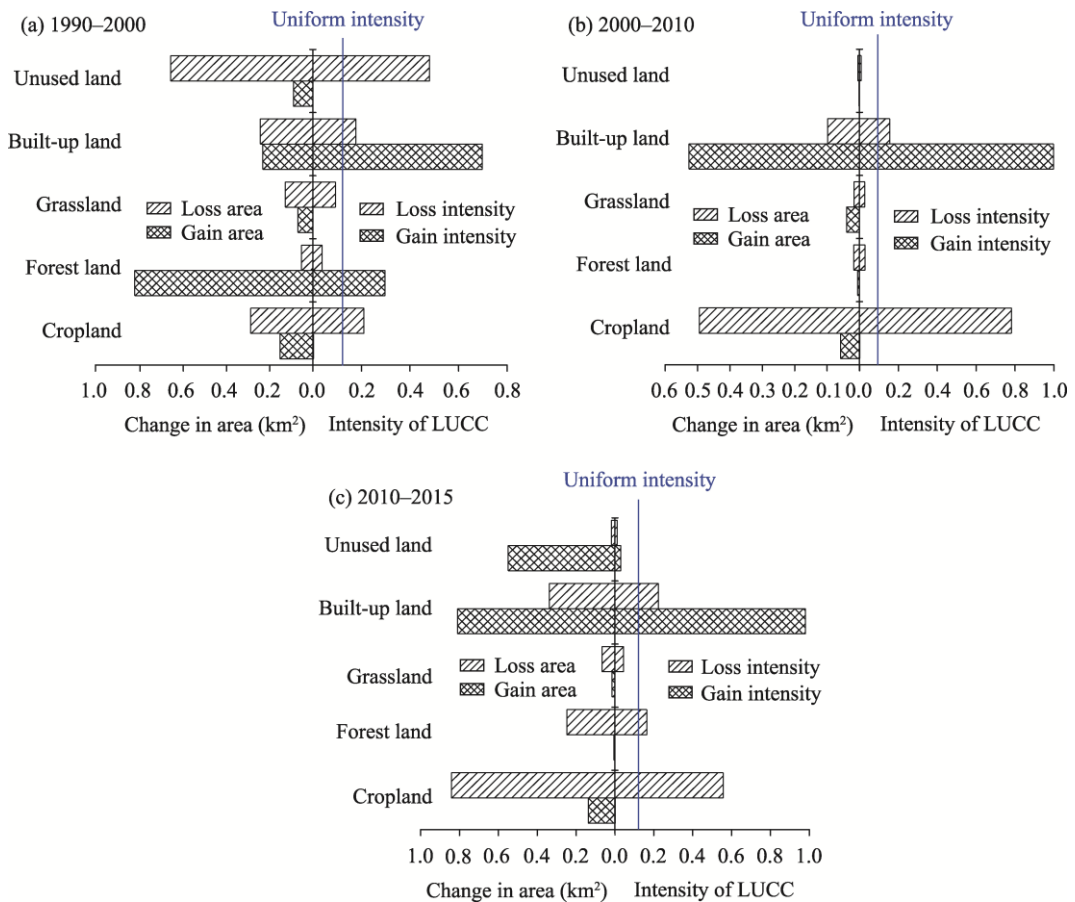
Fig. 3 Change in area and intensity of LUCC at category level in the YNL region during 1990–2000 (a), 2000–2010 (b), and 2010–2015 (c)

3.2.3 Intensity analysis of LUCC at transition level

The intensity analysis at transition level includes two parts: one is the analysis of the gaining LULC type, and the other is the analysis of the losing LULC type. First of all, we investigated the transition intensity of built-up land gaining from other LULC types (Fig. 4). During the three periods of 1990–2000, 2000–2010, and 2010–2015, the transition intensity of cropland was higher than the uniform intensity, and the transition intensity showed a significant upward trend, indicating that the gaining of built-up land was dominated by the losing of cropland. From 2010 to 2015, the transition intensity of forest land to built-up land was higher than the uniform intensity, indicating that the gaining of built-up land tended to be the losing of cropland and forest land, and the losing of cropland was the main reason. The transition intensity of unused land and

grassland in the three periods was less than the uniform intensity. Comprehensive analysis showed that the gaining of built-up land was mainly dominated by the losing of cropland. The spatial expansion of built-up land and the conversion of cropland were the main characteristics of LUCC in the YNL region from 1990 to 2015, which was a typical human land system interaction process in the process of urbanization.
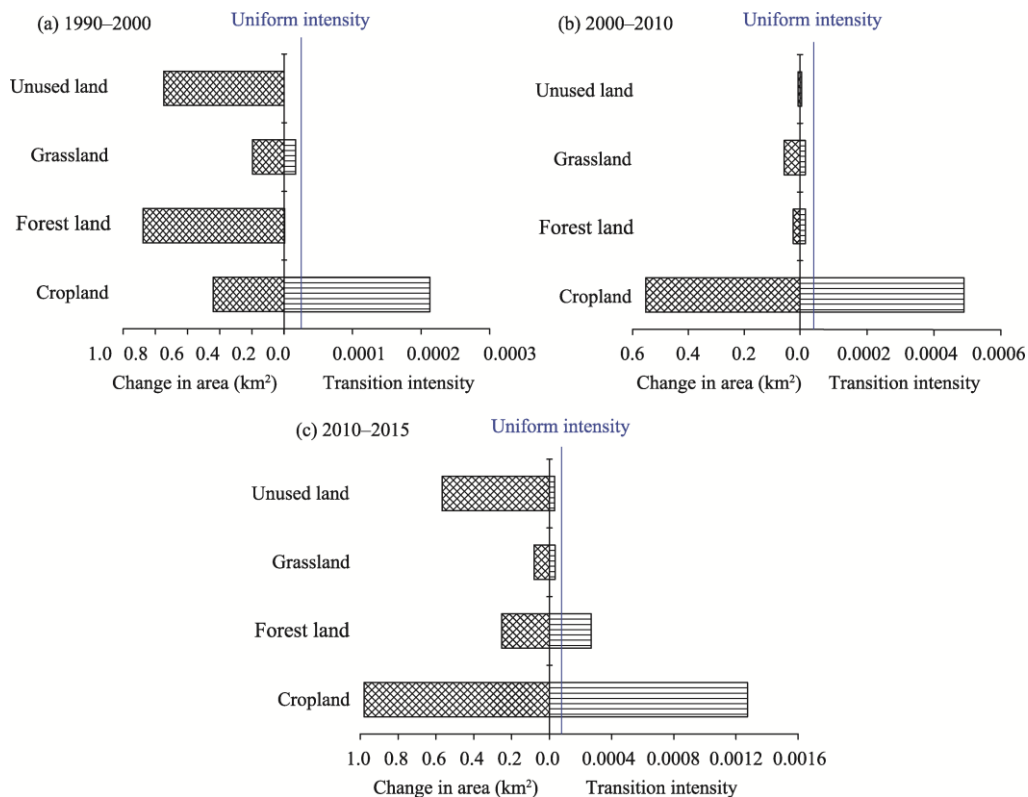

Fig. 4 Change in area and transition intensity of built-up land gaining from other LULC types in the YNL region during 1990–2000 (a), 2000–2010 (b), and 2010–2015 (c)

The transition intensity of grassland losing to other LULC types in the YNL region is shown in Figure 5. It showed that the transition intensity from grassland to built-up land was higher than the uniform intensity, indicating that the losing of grassland was mainly transformed into built-up land. During 1990–2000, the transition intensity from grassland to forest land was also higher than the uniform intensity, but the transition intensity from grassland to forest land was lower than the transition intensity from grassland to built-up land, indicating that the losing of grassland tended to be transformed into built-up land and forest land at this period. The losing of grassland was mainly transformed into built-up land and forest land, which also reflected the rapid urbanization and ecological and environmental protection in the YNL region.

3.3 Transition process of LUCC

We can see the transition process of LUCC from the cross-linking table (Fig. 6). First, during the three periods, the losing of cropland, forest land, and grassland was often transformed into built-up land and the gaining of built-up land also was often transformed from the losing of forest land and cropland. It can be considered that the transition pattern from cropland and forest land to built-up land was a systematic change process of tendency. Second, during the three periods, the gaining of grassland avoided the transition from cropland, forest land, and built-up land and the
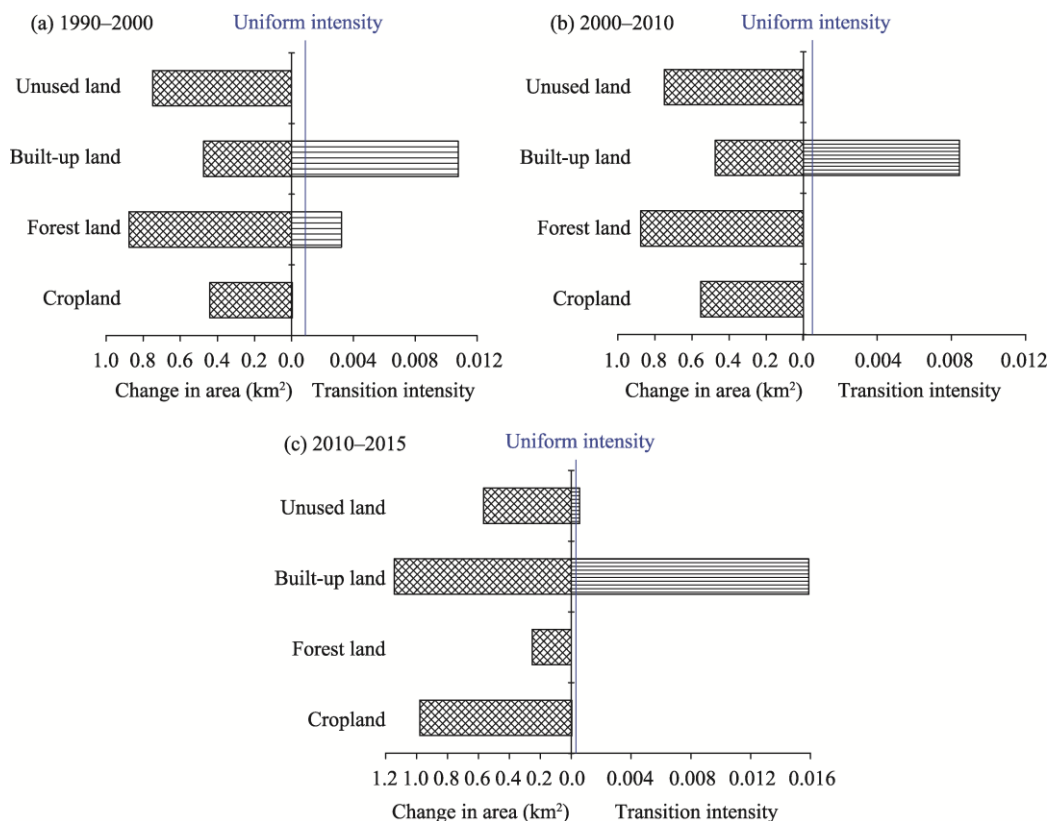
Fig. 5 Change in area and transition intensity of grassland losing to other LULC types in the YNL region during 1990–2000 (a), 2000–2010 (b), and 2010–2015 (c)

losing of grassland and unused land also avoided the transition to cropland. It can be considered that the transition pattern from grassland and unused land to cropland was a systematic change process of avoidance (Fig. 6). The stable transition pattern of LUCC in the YNL region was relatively single from 1990 to 2015. The stability of LUCC was not completely random, but usually driven by obvious natural factors or human activities. LUCC in the YNL region was strongly constrained by natural environmental conditions, which was one of the main reasons for the relatively single and stable transition pattern in the region.

3.4 Analysis of spatial pattern of LUCC

According to the results of spatial distribution of LULC types in the YNL region, we can see that the regional difference of LUCC was obvious (Fig. 7). The distribution of cropland was relatively concentrated, which was mainly distributed in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River, especially in the areas around the counties and towns as well as the regions close to traffic and rivers. The expansion of built-up land was mainly concentrated in the near of counties and towns, as well as the flat terrain in cropland and grassland areas, among which the expansion was most significant in Xigaze City and Lhasa City (Fig. 7b and 7c). There were two main reasons for the expansion. First, on the basis of the original built-up land, the urban area had expanded the occupation of cropland and grassland, i.e., the phenomenon of converting grassland into built-up land, indicating that urban areas had a large demand for built-up land and resources. Second, the phenomenon of converting unused land and grassland into forest land was more obvious in the urban areas, indicating that with the development of urbanization, urban greening was emphasized in the process of urban construction. The area and spatial extent of forest land in Xigaze City and Shannan Prefecture has increased significantly (Fig. 7b and 7d), which was mainly reflected in the transition of grassland and unused land on both sides of the river into forest land, indicating that the overall ecological environment of the region was in the process of improvement.
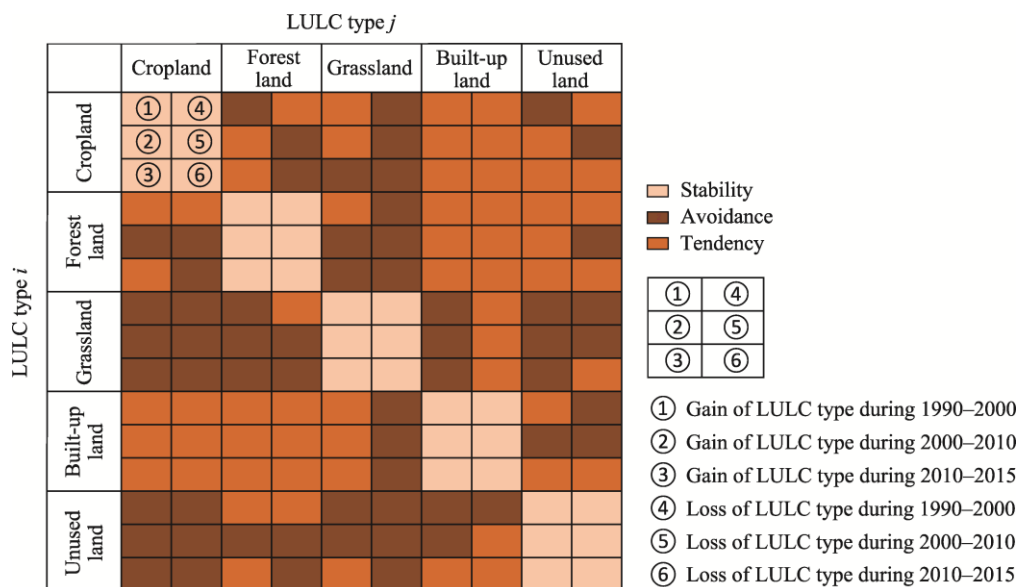
Fig. 6 Process and transition pattern of LUCC in the YNL region from 1990 to 2015. Note: stability, LULC type *i* and LULC type *j* remain constant; avoidance, the gain of LULC type *j* avoids transition from LULC type *i* in the time interval; tendency, the loss of LULC type *i* tends to be transformed to LULC type *j* in the time interval.
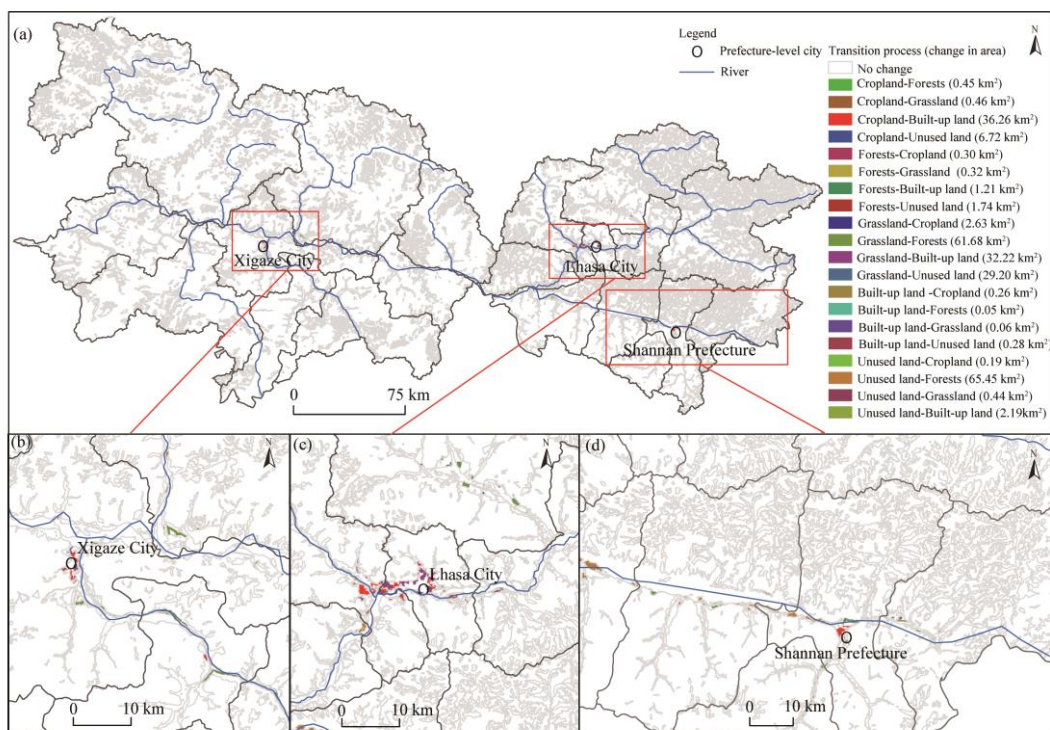

Fig. 7 Spatial distribution and change in area of LUCC in the YNL region (a), Xigaze City (b), Lhasa City (c), and Shannan Prefecture (d) from 1990 to 2015. "–", the transition process from LUCC type to another LUCC type.

4 Discussion

LUCC is a complex evolution process driven by multiple factors, such as the natural environment and social economy. Usually, natural environmental conditions, as internal factors, limit the

spatial distribution of LULC, while human activities, as external drivers, determine the direction and trend of LUCC (Chen et al., 2001; Fan et al., 2003). Topographic factor is one of the key factors determining the spatial distribution of LULC types. It not only provides the basis for the formation of LUCC patterns, but also influences the evolution of LUCC in terms of spatial distribution characteristics (Zhang et al., 2007; Li et al., 2017; Li et al., 2021; Yu et al., 2021). Studies have shown that topographic factors (elevation and slope) and reachability (the distance to rivers and the distance to traffic routes) are the important internal drivers of regional LUCC (He et al., 2016; Tao et al., 2016). Internal drivers have a significant impact on LUCC at large scales and over long periods, while LULC in the short term is mainly influenced by external drivers, such as population, economy, and industrial structure (Wang et al., 2017; Andoh and Lee, 2018). In contrast, population usually affect the whole LUCC pattern by affecting the number of LULC types. Based on these factors, we chose elevation, slope, the distance to rivers, and the distance to traffic routes as internal factors, while population and GDP were chosen as external factors to analyse the mechanisms of LUCC in the YNL region.

4.1 Internal drivers of LUCC

The results of spatial econometric model showed that Moran's I was greater than 0.00 at 1% confidence level, and that all parameter values passed the Z value test, indicating that LUCC in the region was not random, but had obvious positive spatial correlation and spatial dependence. According to the model selection basis, we selected the spatial lag model due to the influencing factors between adjacent units had the obvious spatial correlation (Table 3).

Table 3　Results of spatial econometric model in the YNL region

Parameter	Transition process of LULC types					
	C-B	F-B	G-B	G-F	U-F	G-U
Moran's I	0.46***	0.59***	0.47***	0.57***	0.47***	0.65***
Z value	12.58	5.50	11.84	20.24	20.24	15.20
Lagrange multiplier (lag)	165.99***	35.22***	152.46***	463.60***	247.03***	172.71***
Robust LM (lag)	25.21***	8.69***	27.96***	103.76***	54.65***	24.54***
Lagrange multiplier (error)	143.31***	27.49***	127.03***	365.28***	201.51***	148.30***
Robust LM (error)	2.53	0.96	2.52	5.45	9.13***	0.12
Model selection	Spatial lag model	Spatial lag model	Spatial lag model	Spatial lag model	Spatial lag model	Spatial lag model

Note: C-B, the transition process from cropland to built-up land; F-B, the transition process from forest land to built-up land; G-B, the transition process from grassland to built-up land; G-F, the transition process from grassland to forest land; U-F, the transition process from unused land to forest land; G-U, the transition process from grassland to unused land. *** indicates significant at 1% confidence level.

The results of spatial econometric model between the transition process of six LULC types and driving factors was in line with the actual situation (Table 4). In addition to the transition process from cropland to built-up land, slope had a significant impact on the other five transition processes with a same impact direction, which was the common driving factor affecting LUCC (Table 4). Elevation, the distance to rivers, and the distance to traffic routes also had a significant impact on LUCC. The internal driving factors affecting the transition of LULC types were analysed as follows.

Firstly, in the transition process from cropland to built-up land, there was a significantly negatively correlation between elevation and transition process at 5% confidence level (Table 4). The transition process from cropland to built-up land had a negative correlation with the distance to rivers and the distance to traffic routes, but the correlation was not significant. However, slope was positively correlated with the transition process from cropland to built-up land, and the correlation was not significant. This result showed that compared with slope, the distance to river, the distance to traffic routes, and other factors, elevation was the most important factor affecting the transition process from cropland to built-up land. This reflected that cropland occupied by

built-up land had basically reached saturation, and the natural environmental conditions had an obvious restrictive effect on the expansion of built-up land.

Secondly, in the transition process from forest land to built-up land, there was a negatively correlation between the distance to traffic routes and the transition process at 5% confidence level, while the distance to rivers had a negatively correlation with the transition process from grassland to built-up land at 10% confidence level (Table 4). Slope showed a significant negative correlation at 1% confidence level both the transition process from forest to built-up land and the transition process from grassland to built-up land. This result showed that the closer to traffic routes, the greater the possibility of forest land will be transferred to built-up land. This phenomenon was closely related to the important role of transportation in economic and social development in this region.

Thirdly, in the transition process from grassland to forest land, the transition process was significantly negatively correlated with slope and the distance to rivers at 1% confidence level (Table 4). In the transition process from unused land to forest land, the transition process was significantly negatively correlated with slope and elevation at 1% confidence level, while the transition process was significantly positively correlated with the distance to rivers at 1% confidence level. This phenomenon was closely related to the implementation of ecological protection measures.

Finally, the transition process from grassland to unused land was significantly positively correlated with elevation and the distance to traffic routes at 1% confidence level, and it was significantly negatively correlated with slope at 1% confidence level (Table 4). This situation can be explained by the following situations: (1) areas with small slope were obviously affected by human activities; (2) grassland was occupied and shelved, becoming unused land; and (3) areas with high elevation far from traffic routes were less disturbed by human activities, and grassland degradation was common in this area.

Table 4 Correlation coefficients between LUCC transition process and driving factors using the spatial regression analysis in the YNL region

Driving factor	Transition process of LULC types					
	C-B	F-B	G-B	G-F	U-F	G-U
Elevation	–2.41**	0.52	–0.42	4.49***	–3.11***	4.49***
Slope	0.88	–2.78***	–4.02***	–9.68***	–2.70***	–10.35***
Distance to rivers	–0.22	–0.52	–1.96*	–4.92***	8.42***	1.32
Distance to traffic routes	–1.28	–2.11**	–1.41	0.39	–0.70	12.02***

Note: C-B, the transition process from cropland to built-up land; F-B, the transition process from forest land to built-up land; G-B, the transition process from grassland to built-up land; G-F, the transition process from grassland to forest land; U-F, the transition process from unused land to forest land; G-U, the transition process from grassland to unused. *, **, and *** indicate significant at 10%, 5%, and 1% confidence level, respectively.

4.2 External drivers of LUCC

Land resource is one of the basic elements of economic and social development, and LUCC is an important and effective way to promote the transformation of economic development. We analysed the industrial structure, one of the typical indicators of social and economic development, in the YNL region. The results showed the percentage of primary industry in the region decreased significantly, and the percentage of secondary industry and tertiary industry increased significantly from 1990 to 2015. The development of secondary industry and tertiary industry has increased the demand for built-up land and promoted the expansion of built-up land (Fig. 8).

Population usually affects the overall LUCC pattern by influencing the number of LULC types, the increase of population will directly lead to the increase of built-up land area. Figure 9 showed that the average annual growth rate of urban population was higher than that of rural population in the YNL region during 1990–2000, 2000–2010, and 2010–2015. The average annual growth rate

of rural population was relatively slow and showed a downward trend from 2010 to 2015. This trend was not only related to the large rural population base in the region, but also connected with the rapid development of urbanization. The rapid growth of urban population was the main influencing factor of built-up land expansion.
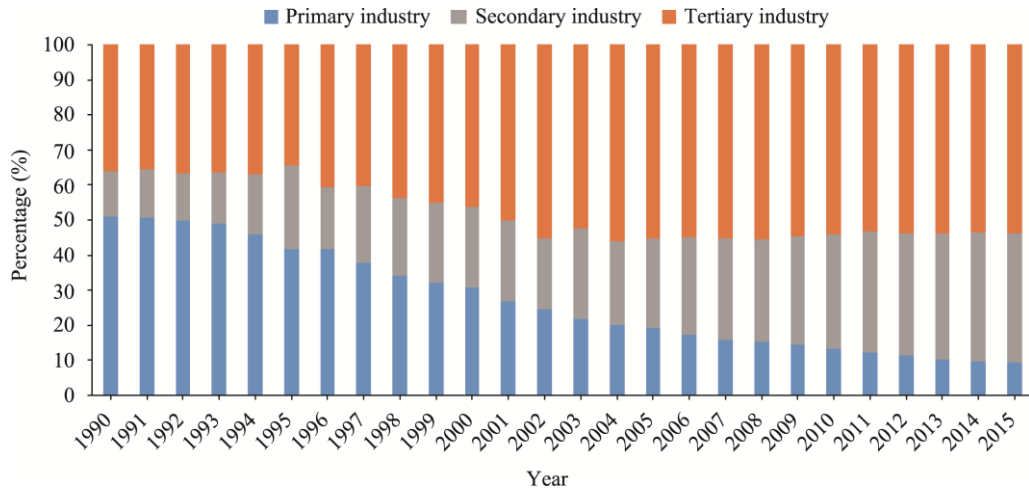

Fig. 8 Percentage of the primary, secondary, and tertiary industries in the YNL region from 1990 to 2015
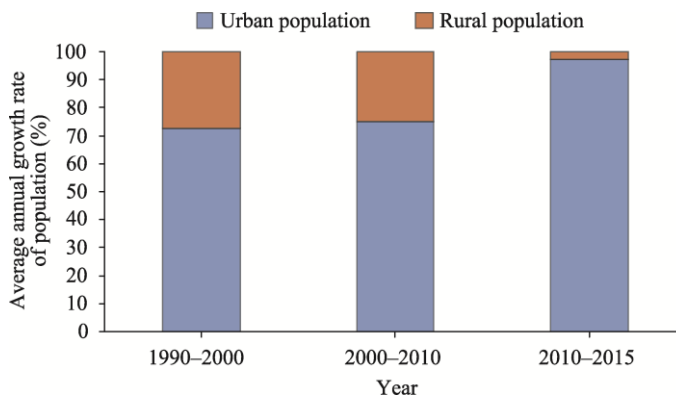

Fig. 9 Average annual growth rate of rural population and urban population in the YNL region from 1990 to 2015. The population data were from the Tibet Statistical Yearbook (Tibet Autonomous Region Statistical Bureau, National Bureau of Statistics Tibet Investigation Corps, 1990–2015).

5   Conclusions

With the rapid development of economy and urbanization, the contradiction between supply and demand of land resources has become a hard constraint on regional economic and social development in the YNL region. Studying the intensity and driving factors of LUCC is of great important to promote the orderly transformation of LULC types and provide a theoretical basis for achieving the sustainable development in this region. This study found that grassland and unused land were the main LULC types in the YNL region during 1990–2015. The change of built-up land and cropland was greatly affected by human activities. The stable transition pattern of LUCC in the YNL region was relatively single from 1990 to 2015, including the transition pattern from cropland and forest land to built-up land was a systematic change process of tendency and the transition pattern from grassland and unused land to cropland was a systematic change process of avoidance. The transition process of LUCC in the YNL region was mainly influenced by natural environment and human activities. In the future, it is suggested to analyse

the explicit and implicit factors affecting LUCC and its response to the ecological environment from a geological perspective, so as to enrich the study of LUCC in this region.

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